http://www.moderntechno.de/index.php/meit/article/view/meit36-00-035
DOI: 10.30890/2567-5273.2024-36-00-035

UDC 536.7

RESEARCH OF THERMOPHYSICAL PROCESSES IN HYBRID POWER PLANTS

Tarazan E.
National Technical University of Ukraine
"Ihor Sikorsky Kyiv Polytechnic Institute"
Lobunko O.
PhD
ORCID: 0000-0001-5273-4768
National Technical University of Ukraine
"Ihor Sikorsky Kyiv Polytechnic Institute"

Abstract. *Over the next decades, changes are predicted in the outline of air vehicle power plants, which, along with traditional requirements, are aimed at meeting environmental standards, minimizing noise levels and fuel consumption. This study is a review of hybrid aircraft power plant schemes, the purpose of which is to present the classification, advantages and possible trends. The main stages of research work on solving the scientific and technical problem of thermal design and research of a hybrid air vehicle power plant are formulated. The need to study and take into account the typical flight trajectory of changes in heat flows and temperature fields of the most thermally stressed components is established. Examples of visualization of the results of monitoring deviations of the measured temperature from the number of missions performed are presented. The creation of an appropriate training course for specialists in the field of hybrid technologies is proposed.*

Key words: *hybrid; power plant; heat engine; heat exchange; thermal fields; thermal management; electric motor.*

Introduction. Hybrid technologies are becoming increasingly relevant in modern vehicles (automobile, aviation, space), as they combine the advantages of different energy sources, contributing to reduced fuel consumption, reduced emissions of harmful substances and improved performance. Aviation power plant – an energy component of an air or aerospace aircraft, designed to implement the available thrust on the corresponding moving object and ensure reliable operation of engines in all flight modes. Aviation power plant combines all aircraft engines installed on the aircraft (main, lifting, combined, auxiliary); systems for attaching engines to the aircraft structure; systems and devices for implementing thrust and regulating its magnitude; systems for ensuring trouble-free operation of engines in all flight modes. A hybrid aircraft powerplant combines traditional internal combustion engines with electric motors, batteries, generators, and other components to create an optimal balance between power, efficiency, and environmental friendliness. For example, some companies are announcing plans to create hybrid aircraft that will use electric systems along with traditional combustion engines (Figure 1).

The topic of hybrid aviation power plants is extremely relevant in the context of general trends in the development of vehicles and the need to minimize fuel consumption and environmental pollution [1]. With increasing awareness of the risks of significant climate change and the problem of environmental pollution, the aviation industry feels the need to find energy-efficient and environmentally friendly solutions [2, 3]. Many years of experience in the use of classic thermal engines using oil-based fuel causes significant amounts of fuel consumption and emissions of harmful substances into the atmosphere. The concepts of hybrid aviation power plants are based on a combination of different energy sources: traditional thermal engines with electrical systems, alternative energy sources, such as solar panels or fuel cells [1-6]. Such concepts of aircraft components are designed to ensure energy efficiency, reduce fuel consumption $G_F \rightarrow min$ and harmful emissions $CO_2 \rightarrow min$, and reduce noise levels. Active research and development is currently underway in the field of hybrid vehicle systems. This includes prototyping, testing different configurations, and evaluating their effectiveness.

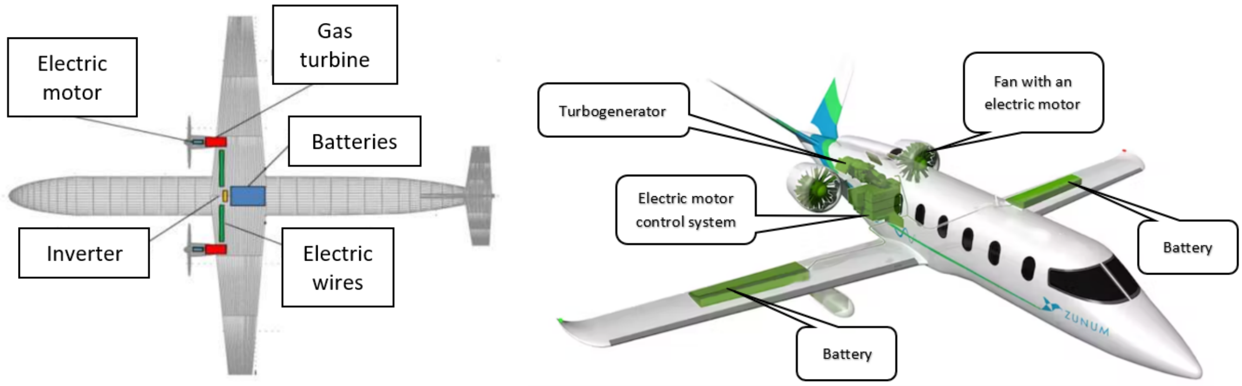

Figure 1 – Hypothetical layout of the components of a hybrid power plant based on an ATR-72-600 passenger aircraft (a) and the aircraft design Zunum Aero ZA-1 (b)

Methods. Computational and analytical studies of parameters and design of hybrid aviation power plants are important stages for achieving the expected efficiency and flight safety. This requires engineering analysis of alternative architectures, computer modeling of work processes, testing and implementation of advanced achievements, technologies and materials, updating of control and management algorithms. An important aspect of creating hybrid aviation power plants is theoretical and experimental justification of the best options for working thermo-gas-dynamic, electrical, electrochemical processes. This will be achieved using constantly updated information technologies, virtual engineering tools and reality.

Main text. The use of hybrid systems allows for improved energy efficiency compared to the characteristics of purely thermal engines. The use of different energy sources and their combination contributes to reducing fuel consumption $(G_F \rightarrow min)$ and reducing emissions of harmful substances $(CO_2 \rightarrow min)$. The calculation of the design parameters of hybrid aircraft power plants consists in determining the power and thrust required for the implementation of typical flights of the aircraft. This requires an analysis of meeting the requirements for flight speed, mass of the aircraft, planned maneuverability and other factors F_X. Typically, this calculation is performed on the basis of aerodynamic studies and modeling of certain flight modes and conditions. The power of hybrid aircraft power plants is determined as the sum of the powers of the thermal and electrical components. The degree of hybridization is calculated by the formulas:

$$H_P = \frac{P_m}{P_{tot}} \qquad (1)$$

$$H_E = \frac{E_b}{E_{tot}} \qquad (2)$$

H_P, H_E – degree of hybridization (P – by power, E – by the amount of energy), P_m – power of the electrical component (electric motor), P_{tot} – total engine system power, E_b – the amount of energy contained in the battery, E_{tot} – total amount of energy of the engine system.

The selection of energy sources for hybrid aircraft power plants is an important stage in the design of the system. There are various factors that should be considered in this selection, including energy efficiency, environmental friendliness, control flexibility and fuel availability. To determine the rational design and layout scheme of the energy source, detailed calculations and analyses are carried out, which take into account factors such as mass M and system dimensions, efficiency E, duration of operation T, cost C and fuel consumption G_F, environmental requirements and other technical limitations. Based on the generalization of publications [1-6], it is possible to distinguish five concepts of structural and layout hybrid schemes (Figure 2, 3): serial, parallel, serial-parallel, turboelectric and fully electric.

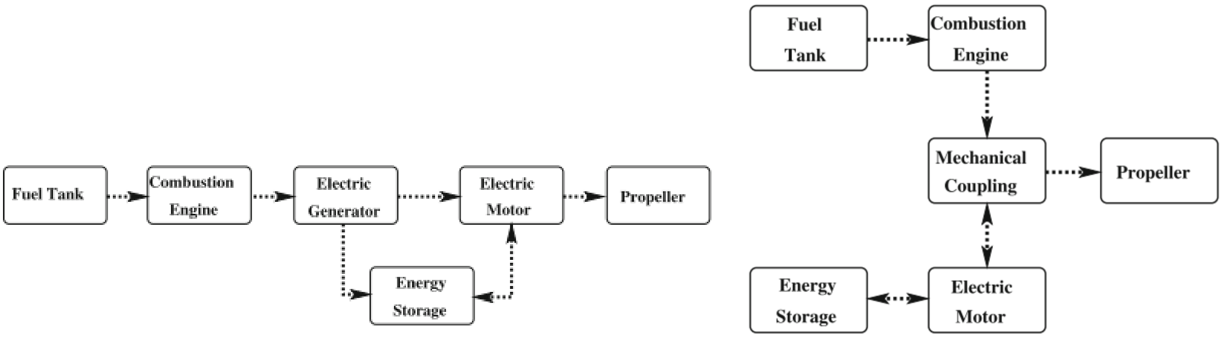

Figure 2 – Series (a) and parallel (b) circuit of a hybrid power plant [3]

Series circuit. In the series circuit (Figure 2), only the electric motor is mechanically connected to the propeller (engine). The heat engine drives an electric generator, the electrical power of which drives the electric motor and charges the batteries. During flight phases requiring a small level of thrust, the energy converted by the generator can charge the batteries. The main advantage of the series circuit is that the heat engine is not mechanically connected to the component that creates thrust and can therefore operate at maximum operating power. On the other hand, the simplicity of the concept ensures ease of motion control. The series configuration is more efficient for high-torque, low-speed applications, but is less efficient than the parallel configuration. This also requires more efficient batteries and electric machines, which increases the mass and volume of the transmission.

Parallel hybrid circuit. In the parallel circuit (Figure 2), two parallel shafts are assumed, with drives from a thermal engine and an electric motor, which are mechanically connected. The shafts of the electric motor and the thermal engine with battery power are connected to the shaft that drives the propeller (engine), so either or both of them can provide thrust. This hybrid circuit also allows charging of batteries when the thermal engine drives the propeller and the electric motor through a coupling. Unlike the series and series-parallel, there is no mechanical connection of the thermal engine with the electric generator. Thermal and electric machines can be smaller, since the driving force $R_{II} f(R_1, R_2)$ provided by both with a corresponding reduction in mass $\downarrow \Delta M_2$. The disadvantages of this configuration are the additional weight ΔM due to mechanical connection and the need for a more complex motion control system. In addition, the operation of a heat engine L_{ICE} may be less optimal at different stages of flight than in a sequential configuration, as it is involved in generating thrust R_2.

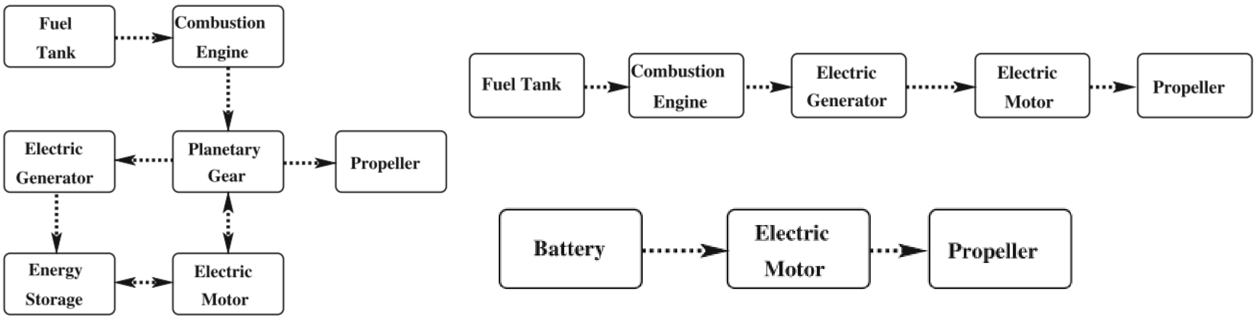

Figure 3 – Series-parallel (c), turboelectric (d) and all-electric (e) powerplant architecture [3]

Series-parallel hybrid scheme. This scheme is a combination of the two previously described (Figure 3). In this scheme, the heat engine, electric motor, electric generator and propeller (engine) are mechanically connected through a coupling (planetary gear). Thus, the mechanical energy of the E_{ICE} heat engine can be used to drive the propeller or converted into electrical energy by a generator to charge the batteries. The main advantage of this configuration is that it allows you to easily change the way the propeller (engine) is driven during operation and is the architecture most often used in hybrid vehicles. The disadvantage of this architecture is the high level of control complexity.

Turbo Electric Hybrid Circuit. This scheme is similar to the series scheme, but does not use a battery. The heat engines are driven by an electric generator, and the electric motors are driven by an electric fan (propeller). All energy comes from fuel combustion, and there are no additional energy storage devices. The advantages of this scheme are similar to those of the series hybrid scheme. Power losses during the conversion of energy from mechanical to electrical and vice versa are minimized by using distributed fans, which increase the degree of double-loop operation $\uparrow m$ while simultaneously reducing the degree of air pressure in the fan π_I.

Fully electric circuit. In an all-electric architecture, batteries are used as the sole source of propulsion for the aircraft. The advantages are the higher energy conversion efficiency of the electric motor compared to a heat engine, as well as the simpler control algorithms required to control a single power source. The main disadvantage is the low efficiency η_b existing battery technologies, making them unsuitable for most types of aircraft. Another disadvantage is that, unlike propulsion heat engines, which operate outside the fuselage and emit heat directly into the atmosphere, electrical devices can be located inside the aircraft, and heating can be a problem. Real devices are not designed to operate in such conditions, and the development of components capable of operating at higher temperatures is relevant.

It is possible to distinguish the main stages of research and development work on solving the scientific and technical problem of designing and researching a hybrid power plant for a promising aircraft (Figure 4).

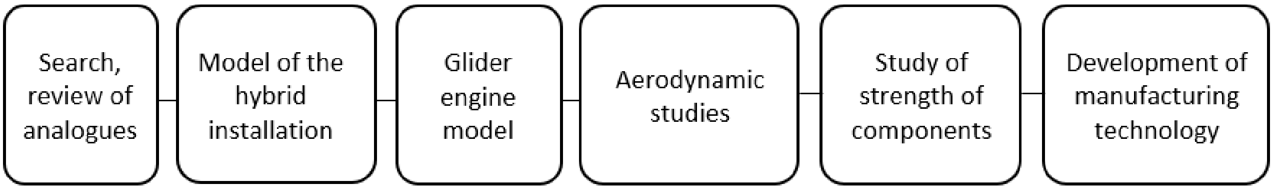

Figure 4 – Main stages of research

Justification of the parameters and characteristics of the components of the hybrid power plant is carried out using software for engineering modeling and 3D design. Calculation and experimental justification involves the creation and use of a model of the hybrid power plant. Model development involves the synthesis of the "glider - hybrid power plant" system. Modeling of the design parameters of hybrid electric motors consists in determining the power $P(T_H, P_H, \tau)$ and traction $R(T_H, P_H, \tau)$, necessary to implement a specific configuration of components and work processes of the vehicle being designed (modernized). This requires a detailed analysis and implementation of speed requirements V, mass M, maneuverability and other factors F_X. This calculation is performed on the basis of aerohydrodynamic studies, computer modeling of individual stationary (Figure 5) and non-stationary modes (low gas, maximum, 0 → small gas, small gas → maximum, maximal → small gas, small gas → 0) and operating conditions ($T_H(\tau)$, $P_H(\tau)$).

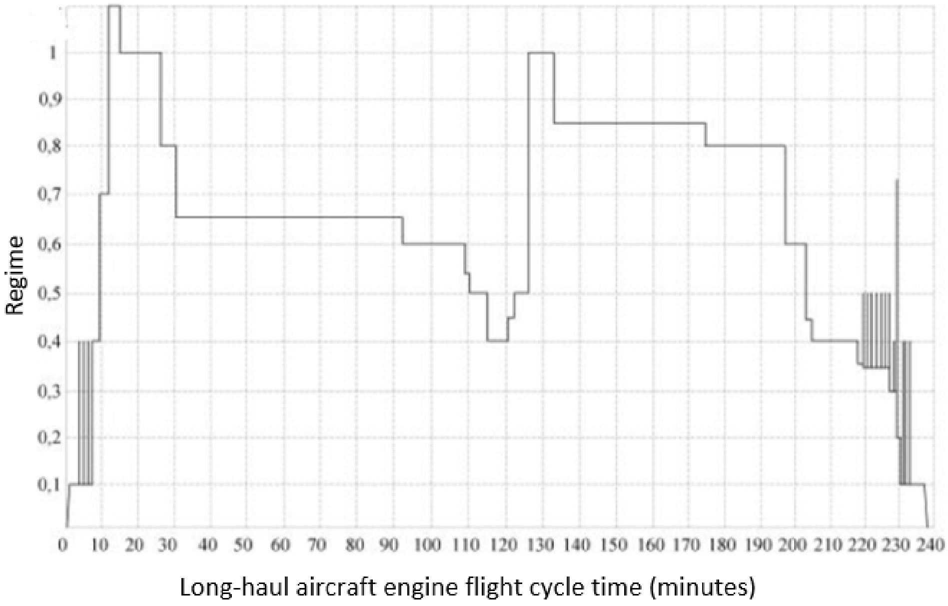

Figure 5

The development of the model involves the synthesis of the "main object – engines" system, thermal analysis and the identification of heat flow sources $Q(\tau)$. The task of thermal analysis is to study changes in the properties of materials of hybrid system components under the influence of temperature. The following thermal parameters of hybrid system component models are studied: temperature fields $T_i(x, y, z, \tau)$, heat loss dimensions η_t, temperature gradients *grad T*, heat flows $Q(\tau)$. It is advisable to take into account the possible trend of changes in the state parameters of the main engine components [11, 12, 13], deviations in the temperature of the working fluid and other determining parameters in diagnostic modes as the number of implemented missions increases (Figure 6).

Thermal field modeling $T_i(x, y, z, \tau)$ used for further determination of thermal stresses $\sigma_{ti}(x, y, z, \tau)$ (due to thermal expansion or compression) in the most critical components during non-stationary operating modes (*low gas, maximum, 0 → small gas, small gas → maximum, maximal → small gas, small gas → 0, change of drive mode "Thermal engine ↔ Electric motor", shutdown) at different stages of movement* ($\tau_1, \tau_2, \ldots, \tau_n$). Numerical modeling of the thermal, stress-strain state, taking into account the cooling system, possible mechanisms of thermomechanical destruction [12] of the main components of the hybrid power plant under expected operating conditions, allows: 1. To justify the choice of materials and technical conditions of manufacture; 2. To specify the requirements and limitations for the most thermally stressed operating modes. The modeling is carried out taking into account probable scenarios of emissions into the atmosphere, the average surface temperature may rise from 2°C to 6°C [3, 4]. Based on the research results, it is planned to develop a methodological apparatus for thermal management of hybrid power plant components and diagnostics of individual parts and assembly units.

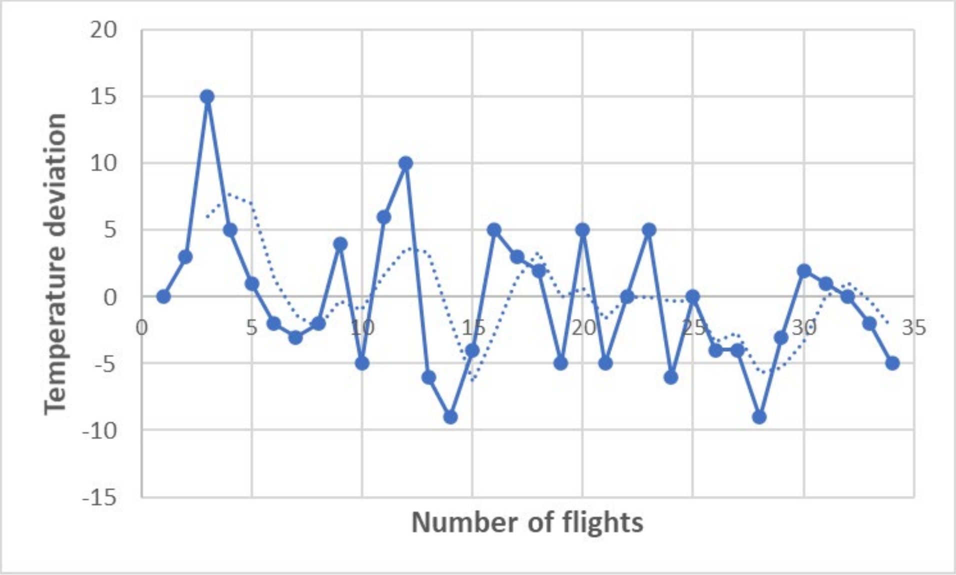

Figure 6

Conclusions. The paper considers the main parameters and design schemes of hybrid aviation power plants. Analysis of scientific publications confirms the relevance of the topic and emphasizes the significance of the development of the theory of hybrid aviation power plants. The working processes and main parameters of hybrid aviation power plants are considered: the degree of hybridization, determination of power and thrust, selection of alternatives and use of energy sources, calculation of mass and dimensions. These parameters are key for the effective functioning of the hybrid system and the main object.

References

1. A Parametric Study of Hybrid Electric Regional Jet Aircraft Design Space (NASA Technical Reports Server). Preparation of Papers for AIAA Journals

2. Design Optimization of Hybrid Electric Aircraft for Maximum Range (IEEE Xplore) Electric/Hybrid-Electric Aircraft Propulsion Systems | IEEE Journals & Magazine | IEEE Xplore

3. Manuel A. Rendón, Carlos D. Sánchez R., Josselyn Gallo M., Alexandre H. Anzai. Aircraft Hybrid-Electric Propulsion: Development Trends, Challenges and Opportunities Journal of Control, Automation and Electrical Systems (2021) 32:1244–1268 https://doi.org/10.1007/s40313-021-00740-x

4. A review on hybrid-electric propulsion systems for aircraft (ScienceDirect) Conceptual design of hybrid-electric transport aircraft - ScienceDirect

5. Benjamin J. Brelje Joaquim R.R.A. Martins (2019). Electric, hybrid, and turboelectric fixed-wing aircraft: A review of concepts, models, and design approaches. Progress in Aerospace Sciences https://doi.org/10.1016/j.paerosci.2018.06.004

6. Edanur Tarazan, Lobunko Oleksandr (2023) Hybrid propulsion systems of aircraft. Intelligence. Integration. Reliability XV international students and young scientists conference 7th December 2023. P. 80-81.

7. Tarazan E., Lobunko O. (2024). Simulation of thermal physical processes in components hybrid vehicles. Modern technologies in industrial production: materials and program of the XI All-Ukrainian scientific and technical conference (Sumy, April 23–26, 2024). P.143-144.

8. Lobunko O.P. Simulation of degradation of individual characteristics of gas turbine engine components. XXXI International scientific and practical conference “Science, worldview and modern youth”. – San Francisco, USA, 2023. – P. 118-123. ISBN – 979-8-89074-562-0, doi – 10.46299/ISG.2023.1.31.

9. Iskra, O., Lobunko, D., Lobunko, O. (2023). Research of mechanisms of destruction and protection complex thermodynamic systems. *European Science*, *1*(sge23-01), 60–77. https://doi.org/10.30890/2709-2313.2023-23-01-015

10. Lobunko, O. (2024). Search for state parameters of thermodynamic models of gas turbine systems with different thrust amounts. *SWorldJournal*, *1*(23-01), 15–22. https://doi.org/10.30888/2663-5712.2024-23-00-009.

11. Lobunko, O. (2024). Scientific and practical aspects of flight safety. European Science, 1(sge26-01), 104-139. https://doi.org/10.30890/2709-2313.2024-26-00-026

Abstract. *Over the next decades, changes are predicted in the outline of air vehicle power plants, which, along with traditional requirements, are aimed at meeting environmental standards, minimizing noise levels and fuel consumption. This study is a review of hybrid aircraft power plant schemes, the purpose of which is to present the classification, advantages and possible trends. The main stages of research work on solving the scientific and technical problem of thermal design and research of a hybrid air vehicle power plant are formulated. The need to study and take into account the typical flight trajectory of changes in heat flows and temperature fields of the most thermally stressed components is established. Examples of visualization of the results of monitoring deviations of the measured temperature from the number of missions performed are presented. The* *creation of an appropriate training course for specialists in the field of hybrid technologies is proposed.*

Key words: *Hybrid; power plant; heat engine; heat exchange; thermal fields; thermal management; electric motor.*

The article is designed: 20.12.2024